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XXII. THE DETERMINATION OF THE LIMENS OF SINGLE AND DUAL IMPRESSION BY THE METHOD OF CONSTANT STIMULI

By E. J. GATES

In their discussions of the method of Constant Stimuli both Müller¹ and Titchener² employ a set of results which were obtained by Riecker in a determination of the two-point limen.³ These results are far from satisfactory; but, although Titchener advocates the use of the method of Constant Stimuli for the determination of the two-point limen, nothing better has as yet appeared. It was our original purpose to repeat Riecker's experiment, not only in the hope of obtaining a more nearly regular set of results, but also as a further test of the method. Later, however, a modification of the experiment, by the admission of a larger number of categories than the usual one-point, two-point and doubtful judgments, seemed advisable. In preliminary experiments, our observers reported that, between the impression of a single point, and that of two discrete points, there occurred a number of impressions which proved to be similar to those which, since the experiments of Henri and Tawney,⁴ Tawney,⁵ and Judd,⁶ are known as 'point,' 'circle,' 'line,' 'dumb-bell,' etc. The method of Right and Wrong Cases regarded these impressions as belonging to the category 'one-point'; but there seemed to be no reason why the judgments 'circle,' 'line,' etc., might not be accepted, and their frequencies treated as psychometric functions, precisely like the 'two-point' judgments. When our experimental work was completed, we submitted the data to Professor Urban, who assured us that, in his opinion, any number of categories might be accepted, and that the notion of psychometric functions was adequate to the treatment of our data.⁷

The Experimental Procedure. Since we set out to repeat Riecker's experiment, we worked on the lower eyelid of the right eye, and we used the same nine *D*'s: 0, 0.5, 1, 1.5, 2, 3, 4, 5, and 6 Paris lines (1 Paris line = 2.27 mm.). We employed the Griesbach aesthesiometer, with a pressure of 10 grams on each point as indicated by the scale of the instrument. We added, however, points of hard rubber, whose weight brought the pressure up to 19.5 gr.; this pressure, as measured by a chemical balance, was fairly constant; and in any case the m. v. of the instrument was probably exceeded by irregularities of applica-

¹ G. E. Müller, *Gesichtspunkte u. Tatsachen d. psychophysischen Methodik*, 1904, 38ff.

² E. B. Titchener, *Experimental Psychology*, 1905, II, i, 92ff.; ii, 250.

³ A. Riecker, *Versuche über den Raumsinn der Kopfhaut*, *Zeit. f. Biologie*, 1874, 177ff.

⁴ V. Henri and G. Tawney, *Ueber die Trugwahrnehmung zweier Punkte bei der Berührung eines Punktes der Haut*, *Philos. Studien*, xi, 1895, 394ff.

⁵ G. Tawney, *The Perception of Two Points not the Space-threshold*, *Psychological Review*, ii, 1895, 585ff.

⁶ C. H. Judd, *Ueber Wahrnehmungen im Gebiete des Tastsinnes*, *Philos. Studien*, xii, 1896, 409ff.

⁷ We are glad to acknowledge our indebtedness to Professor Urban not only for his criticism and advice, which have been most helpful, but also for his interest in our results.

tion, although very great care was taken to handle the aesthesiometer in the same way throughout the experiments. The added points were very slightly conical, and had a terminal diameter of 1.15 mm. The nine *D*'s were arranged by hazard into 100 series, so that every stimulus was presented 100 times, and 900 experiments were performed upon every observer. Those who took part in the experiment were Dr. E. G. Boring (B), then assistant in Psychology; Dr. C. A. Ruckmich (R), then instructor in Psychology; and Asst. Prof. H. P. Weld (W). The observers lay supine on a low couch, with eyes closed; the experimenter sat on a chair at the head of the couch, and, holding the instrument in both hands, gave the ready signal and applied the stimulus. The judgment was given as nearly immediately as might be; and the experimenter, holding the aesthesiometer in his left hand, entered the judgment by a symbol on the record-sheet, and then set the instrument for the next experiment. The whole procedure, from experiment to experiment, occupied 10 or 12 seconds. At the end of the series, however, a longer period (30 to 60 sec.) was allowed, in order to prevent adaptation; and on the resumption of the experiment the beginning of a new series was announced. A few weeks previously, the experimenter had put each one of the observers through a practice-series of 900 experiments, so that the work proceeded with almost machine-like regularity. The experiments were performed between 2.30 and 4 o'clock on three afternoons of the week; a single sitting lasted for about thirty minutes; and in that time about ten series were run off. After the preliminary work was finished, therefore, about four weeks were required for the collection of the data.

In the preliminary experiments the observers were limited to the three usual categories. When it was decided to accept other types of judgment, the observers themselves were allowed to choose their terms. The observations of W and of R are hereafter discussed under the headings 'point,' 'point or circle,' 'circle,' 'circle or line,' 'line,' 'line or dumb-bell,' 'dumb-bell,' 'dumb-bell or two-points,' and 'two-points.'⁸ Observer B adopted only five categories: 'one-point,' 'one-point or extended,' 'extended,' 'extended or two-points,' and 'two-points.' For all observers, the 'or' judgments were regarded as doubtful judgments.

The Results. The results of such an experiment consist, of course, in the numbers expressing the relative frequencies with which the different *D*'s were judged under the different categories. These results are shown in Tables I and II. Before we proceed to their

⁸ These names were, in fact, used only by W. Introspectively, however, R's perceptions so closely resembled those of W, that for purposes of comparison the one set of names may be employed. The principal differences are that for W the third category included impressions which were circular, as if the stimulus was a large blunt point, while for R impressions in this category were slightly oval and nucleated; again, for W the 'line' had a definite width and was rounded at the ends, while R described it as a long narrow oval with two nuclei.

TABLE I
OBSERVED FREQUENCIES OF JUDGMENTS OF THE NINE D's
UNDER NINE CATEGORIES

		Observer W													
<i>D</i>	point	point	circle	circle	circle	line	line	line	d-bell	d-bell	d-bell	two	two	point	
0	81	4	10	..	..	3	..	..	2	2	..	..	..	..	..
0.5	18	2	65	..	..	13	..	..	2	2	..	..	..	..	..
1	13	3	58	8	17	..	..	..	..	..	..	..	1	..	..
1.5	14	2	59	1	14	4	..	..	2	2	..	..	2	..	..
2	11	1	56	5	20	..	..	..	3	3	..	1	3	..	..
3	3	1	29	2	35	7	16	..	..	..	..	3	..	4	..
4	..	..	7	2	24	4	19	13	..	..	..	..	31	..	..
5	..	..	..	..	1	2	3	6	..	..	..	..	88	..	..
6	..	..	..	..	..	..	..	..	..	..	..	..	100	..	..
		Observer R													
<i>D</i>	point	point	circle	circle	circle	line	line	line	d-bell	d-bell	d-bell	two	two	point	
0	53	12	27	1	5	..	..	..	..	..	..	1	..	1	..
0.5	10	7	50	6	17	..	..	..	..	..	..	..	..	..	2
1	4	5	52	8	18	..	..	..	..	..	..	..	..	..	2
1.5	4	11	46	9	16	2	..	..	..	..	..	..	..	..	5
2	9	9	39	4	22	1	10	..	..	..	..	..	..	..	5
3	7	2	22	4	17	1	28	..	..	..	..	..	..	..	17
4	1	..	4	..	6	4	39	..	..	..	..	..	..	..	45
5	..	..	3	..	2	..	15	..	..	..	..	..	..	..	78
6	..	..	..	..	..	2	6	3	..	..	..	..	..	..	89

TABLE II
OBSERVED FREQUENCIES OF JUDGMENTS OF THE NINE D's
UNDER FIVE CATEGORIES

		Observer B				
<i>D</i>	point	point	extended	extended	extended-	two-point
0	89	1	9	..	..	1
0.5	63	2	33	1	1	1
1	56	6	36	1	1	1
1.5	57	3	36	1	..	3
2	51	2	41	2	..	4
3	28	4	50	5	..	13
4	5	2	37	16	..	40
5	1	..	5	5	..	89
6	..	..	..	2	..	98

mathematical treatment, we may call attention to certain facts which the Tables reveal. (1) The relative number of 'or' judgments for all observers is very small. Two hypotheses suggest themselves. There may have been an unconscious tendency to avoid doubtful judgments, due either to the positive tendency to judge under a specific category, or to the mere fact of a considerable number of possibilities of judgment. Or, again, the perceptual experiences may not have 'shaded off' one into another; the regions of particular judgments may have been too large, and the categories too flexible, to permit of other

judgments. This supposition seems to be borne out by another result of Table I. (2) The total number of 'circle' judgments is out of all proportion to the others. At first thought one might suspect a change in standard of judgment; but that is unlikely, since the proportion of these judgments to the total number of judgments is approximately the same for both observers (31% for W, and 29% for R). Apparently, then, either the region was large, or the category admitted a large number of different impressions. Finally, (3) it may be observed that while the curves of frequencies are far from ideal they are yet fairly regular. Observer B has a single inversion of 1%; W has one inversion of 4% and four of 3% or less; R has one of 6%, two of 5%, and five of 3% or less.

The method of treating results where more than three categories are admitted has been indicated by Urban in his examination of Keller's acoumetrical experiments.⁹ In these experiments five kinds of judgments were allowed; and since, in our experiments, B also had five categories, the method of treatment in the two cases is so far identical. The procedure, in brief, is as follows. We first determine in the usual way the constants for the psychometric functions of the One-point judgments, and for those of the Two-point judgments. Their curves obviously give the boundary, on the one hand between the One-point and the Point-extended judgments, and on the other hand between the Two-point and the Two-point-extended judgments. If, now, we combine the frequencies of the One-point and of the

TABLE III

Boundary	h'	c'	h	c	L	Interval
1-1X.....	—.1963	0.5350	—.3926	—0.6428	1.636	
1X-X.....	.2220	—0.6211	.4440	0.7110	1.601	—0.035
X-X2.....	.2781	0.4040	.5562	2.0726	3.724	2.123
X2-2.....	.2867	0.5639	.5734	2.2841	3.980	0.256
Observer B						
p-pc.....	—.1642	1.3180	—.3284	0.3328	—1.012	
pc-c.....	—.1712	1.3900	—.3424	0.3628	—1.060	—0.048
c-c1.....	—.1989	0.4601	—.3978	—0.7333	1.843	2.903
c1-1.....	—.2117	0.3891	—.4234	—0.8811	2.081	0.238
1-1db.....	.2455	—0.0837	.4910	1.3893	2.830	0.749
1db-db ..	.2440	—0.0379	.4880	1.4261	2.923	0.093
db-db2...	.2328	0.4713	.4656	1.8681	4.012	1.009
db2-2....	.2333	0.5225	.4666	1.9323	4.150	0.138
Observer R						
p-pc.....	—.2826	1.5970	—.5652	—0.0986	0.174	
pc-c.....	—.2909.	1.5880	.5818	—0.1574	0.270	0.096
c-c1.....	—.2570	0.4266	.5140	—1.1154	2.170	1.900
c1-1.....	.2396	—0.2553	.4792	1.1823	2.467	0.297
1-1db....	.2682	0.2379	.5364	1.8471	3.438	0.971
1db-db ..	.2735	0.3102	.5470	1.9512	3.567	0.129
db-db2...	.3154	0.6030	.6308	2.4950	3.960	0.393
db2-2....	.3316	0.7029	.6632	2.6927	4.060	0.100
Observer W						

⁹ F. M. Urban, Ueber die Methode der mehrfachen Fälle, *Arch. f. d. ges. Psychologie*, xvii, 1910, 380-387.

Point-extended judgments, and determine their constants, we shall obtain the lower boundary of the Extended judgments; and again, if we combine the psychometric functions of the Two-point judgments and those of the Two-point-extended judgments, and determine their constants, we shall obtain the upper boundary of the Extended judgments.

The same process of calculation applies when more than five judgments are accepted. We successively combine the frequencies from the two extremes, until we arrive at three or two judgments. Where five categories are employed, as by B, we arrive at four boundaries; where there are nine kinds of judgment, as in the cases of R and W, there are eight boundaries, since the lowermost and the uppermost boundary in every case is infinity. The constants of the psychometric functions which give the curves of these boundaries are shown in columns 3 and 4 of Table III. The values of h' and c' are derived from the normal equations of the method of least squares. The quantities necessary for setting up these equations were obtained from Urban's tables.¹⁰ The values of h and c are derived from h' and c' ; $h = h'/d$, where $d = 0.5$, and $c = 3h + c'$. The limens, which are derived from h and c , $L = c/h$, are presented in the fifth column of the table. In the sixth column are to be found the intervals of uncertainty. The interval represents in any case the difference between the upper and the lower boundary; for us it represents the area of the region covered by a category.

An inspection of the table reveals inversions of the first two categories by B and R. B's inversions, however, are very slight, in the second decimal; those of R are negative. The first of these probably means that even one point is judged as 'point or circle' more often than 'point.' The sense of the second seems to be that the tendency to give 'point' judgments for the least separation (0.5 Paris line) is equal to (or slightly greater than) the tendency to judge 'point' at no separation. There is good agreement as regards the Two-point limen: the average for all three observers is $4.06 \pm .08$. Riecker's Two-point limen was 1.88, a value which for our observers is approximately the limen of the first lower boundary of the third category. Riecker, apparently, either ran foul of the stimulus error, or purposely included the intra-cutaneous impressions in his Two-point judgments. The intervals of uncertainty are what we should expect from an inspection of the table of frequencies. Although it is here that the experiment is seen at its worst, we cannot say whether the irregularities are due to some inherent irregularity in the perceptual patterns, or whether they result from a change in standard of judgment. The observers reported a difficulty in maintaining the same standard and regretted that they had not had extended practice-series with the new categories. It is remarkable, on the other hand, that the interval of 'circle' is the largest interval for both R and W; that the size of this interval closely resembles that of B's 'extended'; that for W the intervals of circle, line and dumb-bell become progressively smaller as the two-point limen is approached; and that a similar relation is found between W's 'or' judgments. Aside from the fact that R's intervals do not show these relations so regularly, they differ materially from those of W only in the size of the interval for 'dumb-bell.'

In conclusion we may say that, if we were repeating the experiment,

¹⁰ F. M. Urban, Hilfstabellen f. d. Konstanzmethode, *Arch. f. d. ges. Psychol.*, xxiv, 1912, 236ff.

we should give our observers the benefit of greater practice in judgment under the various accepted categories. We believe that a better set of *D*'s could be found; and we are sure that the cutaneous area chosen is not the best possible. We should take introspections at the close of each day's work.

APPENDIX

The following figures were obtained by a pair of students in the regular work of the laboratory course in Quantitative Psychology. The *E* was G. J. Rich, the *O* was F. L. Dimmick. The method of procedure, the *D*'s, the cutaneous area, etc., were the same as in our experiment. Five categories were admitted: point, circle, oval, long-oval, two-point. Fifty series were made. In the calculation, the five categories were reduced to three in the way described above, and the directions in Titchener's Manual were then followed. The quantities for the equations were taken from Urban's tables. The results are:

Boundary	<i>h'</i>	<i>c'</i>	<i>h</i>	<i>c</i>	<i>L</i>
pt-circle.....	.1839	-0.9092	.3678	0.1942	0.528
c-oval.....	.2158	-0.2471	.4316	1.0577	2.451
o-lo.....	.2353	-0.2903	.4706	1.1215	2.383
lo-2.....	.2913	1.2110	.5826	2.8688	4.924

The figures are a sample of the sort of results that may be obtained by conscientious work in a limited period of time (4 afternoons), by students who have had only the practice that the laboratory drill-course affords.